

MODELLING AND PERFORMANCE EVALUATION OF FREE SPACE
OPTICAL LINK FOR GROUND-TO-TRAIN COMMUNICATIONS

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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*“To Almighty Allah, who gave me strength and wisdom to complete this work,
To my beloved family, my dear father and mother. To my brothers Dr. Wael, Dr.
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PERPUSTAKAAN TUNKU TUN AMINAH

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ABSTRACT

There is an increased demand for high-speed train (HSR) services. Consequently, onboard high-speed internet access needs increased as passengers travel to and from work. This sudden surge in demand introduced new challenges in delivering a seamless internet connection on-board fast-moving trains. Free Space Optical (FSO) Communications technology promises a bright future for various applications, due to its cost-effectiveness, ease of deployment, and huge unregulated bandwidth, which gives it an edge over contemporary technologies. However, there is a lack of significant research on FSO links for railway communications. In this thesis, straight, curved, and new double curved tracks mathematical models for FSO Ground-to-train (G2T-FSO) links have been proposed to overcome this issue and satisfy increased demand. G2T-FSO links feature base stations located beside the track to provide a LOS link for traveling trains. Moreover, FSO links comprise of intensity modulated transmitters with Direct detection receiver, that utilize RZ and NRZ OOK modulation formats at 2.5 Gbps. In addition, multiple transmitters concept has been implemented to enhance the link performance, in which single, dual, triple, and quad transmitters have been developed. Furthermore, geometrical parameters have been optimized to achieve optimal link performance. Measured meteorological data have been incorporated to simulate rain and fog weather attenuations. Performance evaluation has been conducted in terms of Received power, Q factor, SNR, BER, and Eye diagram patterns using MATLAB® and Optisystem®. Simulation results show significant effects of geometrical and atmospheric losses on single and dual transmitters link performances. However, Quad and triple transmitters have obtained a feasible error-free G2T-FSO link with BER of 10^{-9} for NRZ and RZ formats, significantly enhanced ranges of up to 680m for straight track and 618m for curved track under clear weather condition have been achieved. G2T-FSO links promise an unmatched performance over contemporary HSR communications technology.

ABSTRAK

Terdapat peningkatan permintaan untuk perkhidmatan kereta api berkelajuan tinggi. Oleh yang demikian, keperluan akses internet berkelajuan tinggi meningkat semasa pekerja pergi dan balik kerja. Pertambahan mendadak dalam keperluan ini telah menyebabkan cabaran baharu dalam memberikan hubungan internet selanjar bagi keretapi laju. Teknologi Komunikasi Optik *Free Space* (FSO) menjanjikan masa depan yang cerah bagi pelbagai aplikasi, disebabkan oleh kos-efektif, kemudahan mengatur kedudukan, dan jalur lebar yang besar serta tidak terkawal, yang membolehkannya keluar daripada teknologi yang kontemporari. Bagaimanapun, terdapat kurang kajian yang penting ke atas hubungan FSO untuk komunikasi kereta api. Dalam tesis ini, hubungan model matematik bagi track lurus, keluk, dan dua keluk baharu untuk Ground-to-train FSO (G2T-FSO) telah dicadangkan untuk menangani isu ini dan memenuhi peningkatan keperluan. Hubungan G2T-FSO menyediakan stesen penempatan yang terletak di sebelah trek untuk menyediakan hubungan LOS untuk kereta api yang bergerak. Tambahan pula, hubungan FSO merangkumi kekuatan pemancar modulasi dengan penerima pengesanan langsung, yang menggunakan format modulasi RZ dan NRZ OOK pada 2.5 Gbps. Tambahan lagi, konsep pemancar pelbagai telah dilaksanakan untuk menggalakkan prestasi hubungan, yang mana pemancar tunggal, ganda dua, ganda tiga dan ganda empat telah dibentuk. Lagi pula, parameter geometri telah dioptimumkan untuk mencapai prestasi hubungan optimum. Data meteorologikal yang diukur telah digabungkan untuk simulasi cuaca hujan dan kabut lemah. Penilaian prestasi telah dijalankan dalam hal Penerimaan kuasa, faktor Q, SNR, BER, dan corak rajah Mata menggunakan MATLAB® dan Optisystem®. Keputusan simulasi menunjukkan kesan penting pada kehilangan prestasi hubungan geometrikal dan atmosfera ke atas pemancar tunggal dan ganda dua. Bagaimanapun, pemancar ganda empat dan ganda tiga menerima hubungan bebas-kesalahan sesuai dengan BER bagi 10^{-9} untuk format NRZ dan RZ, pertingkatkan julat yang hetva

680 m untuk trek lurus dan 618 m untuk trek keluk di bawah keadaan cuaca cerah telah dicapai. Hubungan G2T-FSO menjanjikan prestasi tiada bandingan terhadap teknologi komunikasi kontemporari HSR



TABLES OF CONTENTS

TITLE	i
DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
ABSTRACT	vi
ABSTRAK	vii
TABLES OF CONTENTS	ix
LIST OF FIGURES	xiv
LIST OF TABLES	xx
LIST OF APPENDICES	xxii
LIST OF SYMBOLS	xxiii
LIST OF ABBREVIATIONS	xxvii
LIST OF PUBLICATIONS	xxx
CHAPTER 1 INTRODUCTION	1
1.1 Research background	1
1.2 Research Problem Statement	3
1.3 Research Objectives	5
1.4 Scope of Research	6
1.5 Research Significance	8
1.6 Thesis Structure Outline	8
CHAPTER 2 LITERATURE REVIEW	10
2.1 Introduction	10
2.2 Railway Communication Systems	10
2.2.1 Railway Communications Services	14

2.2.2	Train-to-Ground Wireless communications scenarios	15
2.2.3	Challenges and Opportunities	20
2.2.4	Contemporary Technologies for Internet Access Onboard Trains	23
2.3	Free Space Optical Communications	25
2.3.1.1	Basic Components and Operation	28
2.3.1.2	FSO Link physical configurations	30
2.3.1.3	FSO Advantages and Features	34
2.3.1.4	FSO Applications and Possibilities	36
2.3.1.5	FSO Challenges and Mitigation Techniques	38
2.3.1.6	FSO Eye Safety and Regulations	39
2.3.2	Optical Sources and Modulators	42
2.3.2.1	Digital Baseband Modulation	46
2.3.2.2	On-Off-Keying (NRZ) and (RZ)	47
2.3.3	FSO Channel	48
2.3.3.1	FSO Atmospheric Medium Characteristics	48
2.3.3.2	Absorption and Scattering losses	50
2.3.3.3	Loss due to Weather conditions	54
2.3.3.4	Optical system losses	56
2.3.3.5	Geometrical loss	57
2.3.3.6	FSO Photodetection Configurations	58
2.3.3.7	Noises in Photodetection process	60
2.3.4	FSO link Performance Measures	61
2.3.4.1	Signal-to-Noise Ratio (SNR)	62
2.3.4.2	Bit-Error-Rate (BER)	62
2.3.4.3	Q-factor	63
2.3.4.4	Eye Patterns	63
2.4	FSO links for Ground-to-Train communications	65
2.4.1	Research Gap	69
2.5	Summary	75
CHAPTER 3	MODELING OF G2T-FSO COMMUNICATION LINKS.	76
3.1	Introduction	76

3.2	Research Framework	76
3.3	G2T-FSO Geometrical Models	78
3.3.1	Straight Track G2T-FSO Model	78
3.3.1.1	Geometrical Properties	80
3.3.1.2	Received Power	82
3.3.1.3	Geometrical loss	83
3.3.2	Considerations for Horizontal Alignment Radius and Physical Behavior of the Vehicle On a Curve:	84
3.3.3	Single Curved Track G2T-FSO Model	88
3.3.3.1	Geometrical Properties	89
3.3.3.2	Received Power	92
3.3.3.3	Geometrical loss	93
3.3.4	Double Curved Track G2T-FSO Model	93
3.3.4.1	Geometrical Properties	94
3.3.4.2	Received Power	98
3.3.4.3	Geometrical Loss	98
3.4	Summary	99
CHAPTER 4	103G2T-FSO LINK GEOMETRICAL PARAMETERS OPTIMIZATION AND SIMULATION SETUP	103
4.1	Introduction	103
4.2	Geometrical Models Parameters Optimization	103
4.2.1	Straight Track	104
4.2.2	Curved and Double Curved Track	107
4.3	FSO Communication Link Model Optisystem Simulation	112
4.3.1	G2T-FSO Models	113
4.3.1.1	OOK-NRZ Transmitter Model	113
4.3.1.2	OOK-RZ Transmitter Model	114
4.3.1.3	Multiple Transmitters Approach	115
4.3.2	Channel Modeling	117
4.3.2.1	Rain Attenuation	118
4.3.2.2	Fog Attenuation	120
4.3.3	Receiver Performance Evaluation	122

4.4	G2T-FSO links Optisystem Simulation Parameters	124
4.5	Summary	126

CHAPTER 5 PERFORMANCE EVALUATION OF G2T-FSO

COMMUNICATION LINK MODELS 127

5.1	Introduction	127
5.1.1	Straight Track G2T-FSO OOK-NRZ modulated lin	127
5.1.1.1	Received Power	127
5.1.1.2	SNR	129
5.1.1.3	BER and Eye Diagrams	130
5.1.2	OOK-RZ	133
5.1.2.1	Received Power	133
5.1.2.2	SNR	134
5.1.2.3	BER and Eye Diagrams	135
5.1.3	G2T-FSO Straight Track Overall Performance Evaluation	138
5.1.3.1	NRZ and RZ Transmitters Comparison	139
5.1.3.2	Comparison of Straight Track G2T-FSO Related Research	140
5.2	Curved Track Performance Evaluation Results	142
5.2.1	OOK-NRZ	142
5.2.1.1	Received Power	142
5.2.1.2	SNR	143
5.2.1.3	BER and Eye Diagrams	144
5.2.2	OOK-RZ	147
5.2.2.1	Received Power	147
5.2.2.2	SNR	148
5.2.2.3	BER and Eye Diagrams	149
5.3	Double Curved Performance Evaluation Results	152
5.3.1	OOK-NRZ	152
5.3.1.1	Received Power	152
5.3.1.2	SNR	153
5.3.1.3	BER and Eye Diagrams	154
5.3.2	OOK-RZ	157

5.3.2.1	Received Power	157
5.3.2.2	SNR	158
5.3.2.3	BER and Eye Diagrams	159
5.3.3	G2T-FSO Single and Double Curved Track Overall Performance Evaluation	162
5.3.3.1	Effects of Track Clearance on Single and Double Curved Track G2T-FSO link	163
5.3.3.2	Effects of Radius Length Variation On Curved and Double Curved Track G2T-FSO link	164
5.3.3.3	Comparison of Curved Track G2T-FSO Related Research	166
5.3.4	Summary	167

CHAPTER 6 FEASIBILITY ANALYSIS OF G2T-FSO COMMUNICATION

LINK MODELS 168

6.1	Introduction	168
6.2	Straight Track Feasibility Analysis	169
6.2.1	Link Margin Analysis Results	169
6.2.2	Number of Required Base Stations	170
6.3	Curved Track and Double Curved Feasibility Analysis	175
6.3.1	Link Margin Analysis Results	175
6.3.2	Required Number of Base Stations	176
6.4	Summary	180

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS 181

7.1	Conclusions	181
7.2	Contributions	182
7.3	Recommendations for Future Work	183

REFERENCES 185

APPENDICES 199

VITA 229

LIST OF FIGURES

1.1	High-End devices traffic trend multiplication	1
1.2	Cisco internet growth forecasts form 2017 to 2022	2
1.3	Modeling and performance evaluation of G2T-FSO links K-Chart	7
2.1	Evolution of railway locomotives and signaling technologies	11
2.2	Classification of railway communication technologies	12
2.3	GSM-R configuration and services	13
2.4	Classification of main railway communications services	15
2.5	Typical train to trackside wireless communication configuration	16
2.6	Relative wayside antenna height to train antenna in viaduct configuration	17
2.7	Land cutting HSR wireless communications	18
2.8	Railway Tunnel (a) Leaky coaxial cable. (b) DAS communications	19
2.9	(a)The networked-train services (b) Railway communications dilemma	21
2.10	IEEE802.11p standard for the intelligent transportation system	23
2.11	Typical configurations and technologies used for internet access onboard trains	24
2.12	FSO communications versus other technologies	26
2.13	Electromagnetic spectrum bands	27
2.14	International commission on illumination infrared emission classes	28
2.15	Basic FSO link components	29
2.16	FSO links line of sight classifications	30

2.17	(a) Direct. and (b)Non-Direct. LOS configuration	31
2.18	Field of view angle	32
2.19	Diffused link configuration	32
2.20	Tracked link configuration	33
2.21	FSO networks topologies	34
2.22	V2V Intelligent transportation FSO communication	38
2.23	Pictorial representation of light absorption in the eye for different wavelengths	40
2.24	Stimulated emission stages	43
2.25	Common optical modulators (a)Internal. (b) External	46
2.26	Modulation tree	47
2.27	NRZ and RZ modulation format	48
2.28	Absorption contribution to atmospheric transmittance windows	50
2.29	Scattering classes and their configuration	51
2.30	(a) Rain rate vs. attenuation Carbonneau and Wisely. (b)Fog attenuation for $\lambda=850\text{nm}$ utilizing Kim model	56
2.31	Beam divergence	57
2.32	FSO Non-Coherent Direct-Detection configuration	58
2.33	FSO coherent detection configuration	59
2.37	Eye pattern constituents and typical ideal eye diagrams for NRZ and RZ (50%)	63
2.38	Eye diagrams measurable characteristics	64
2.39	G2T-FSO communication link prototype	65
2.40	Prototype implementation method (a) Fan-shaped laser beam.	66
2.41	Shinkansen G2T-FSO communication link experimental field tests	67
2.42	Turbulence investigation of FSO link experimental setup	68
2.43	Lambertian G2T-FSO link model	69
3.1	Flowchart of methodology	77
3.2	Research implementation stages	78
3.3	Proposed straight track G2T-FSO model	79
3.4	Straight track G2T-FSO link geometrical setup	79

3.5	Straight track G2T-FSO model geometrical layout	80
3.6	Train motion in a curved section of the track	84
3.7	Single wheelset motion in curvature of the track	85
3.8	Effect of various driving speeds on curved track radius	87
3.9	Proposed curved track G2T-FSO model layout	88
3.10	Curved track G2T-FSO link geometrical properties	89
3.11	Curved track G2T-FSO link LOS considerations	91
3.12	Proposed double curved track G2T-FSO model layout	93
3.13	Double curved track G2T-FSO link geometrical properties	94
3.14	Double curved track G2T-FSO link LOS considerations	97
4.1	Straight track G2T-FSO link model divergence angles for various values of (a) d _{VS} and (b) d _{HS}	104
4.2	Straight track G2T-FSO link geometrical loss for various values of (a)d _{VS} and (b)d _{HS}	105
4.3	Straight track, G2T-FSO link theoretical, received power for geometrical loss for various values of (a) d _{VS} and (b)d _{HS}	106
4.4	Curved tracks G2T-FSO link model divergence angles for various values of (a) d _{VC1} . and (b) d _{VC2}	108
4.5	Curved tracks G2T-FSO link model divergence angles for various values of (a) d _{HC1} . and (b) d _{HC2}	108
4.6	Curved tracks G2T-FSO link model geometrical loss for various values of (a) d _{VC1} . and(b) d _{VC2}	109
4.7	Curved tracks G2T-FSO link model geometrical loss for various values of (a)d _{HC1} . and (b) d _{HC2}	109
4.8	Curved tracks G2T-FSO link theoretical received power for various values of (a) d _{VC1} . and (b) d _{VC2}	110
4.9	Curved tracks G2T-FSO link theoretical received power for various values of (a)d _{HC1} . and (b) d _{HC2}	111
4.10	FSO link block diagram(Optisystem)	112
4.11	G2T-FSO OOK NRZ transmitter (a) Block diagram. (b) Electrical signal and optical spectrum	113
4.12	G2T-FSO OOK RZ transmitter (a) Block diagram. (b) Electrical signal and optical spectrum	114

4.13	Multiple transmitters configuration	115
4.14	Single G2T-FSO transmitter Optisystem model (1Tx/1Rx)	116
4.15	Dual G2T-FSO transmitters Optisystem model (2Tx/1Rx)	116
4.16	Triple G2T-FSO transmitters Optisystem model (3Tx/1Rx)	117
4.17	Quad G2T-FSO transmitters Optisystem model (4Tx/1Rx)	117
4.18	Maximum rain rate [Batu Pahat station Latitude (1o52'N, Longitude 102o59'E)(2013-2015)]	119
4.19	Specific rain attenuation.[Batu Pahat station Latitude (1o52'N, Longitude 102o59'E)(2013-2015)]	119
4.20	Visibility frequency histogram occurrence. [Batu Pahat Station Latitude (1o52'N, Longitude 102o59'E)(2013-2015)]	121
4.21	Visibility cumulative percentage of the occurrence. [Batu Pahat Station Latitude (1o52'N, Longitude 102o59'E)(2013-2015)]	121
5.1	Received power of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO straight track link	128
5.2	SNR of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO straight track link	129
5.3	BER of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO straight track link	130
5.4	Received power of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d)4Tx/1Rx. transmitters for RZ modulated G2T-FSO straight track link	133
5.5	SNR of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO straight track link	134
5.6	BER of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO straight track link	135
5.7	NRZ transmitter versus RZ transmitters received power for straight G2T-FSO	139
5.8	G2T-FSO straight track previous studies comparison	141
5.9	Received power (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO curved track link	142

5.10	SNR of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO curved track link	144
5.11	BER of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO curved track link	145
5.12	Received power of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO curved track link	147
5.13	SNR of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO curved track link	148
5.14	BER of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO curved track link	149
5.15	Received power of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO second curved track link	153
5.16	SNR of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO second curved track link	154
5.17	BER of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for NRZ modulated G2T-FSO second curved track link	155
5.18	Received power of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO second curved track link	157
5.19	SNR of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO second curved track link	158
5.20	BER of (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx. transmitters for RZ modulated G2T-FSO second curved track link	159
5.21	Effects of track clearance on first and second Track for NRZ and RZ transmitters	163

5.22	Variation in received power for RC1,C2(200), RC1,C2(200) and RC1,C2(300) for (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx NRZ transmitters	164
5.23	Variation in received power for RC1,C2(200), RC1,C2(250) and RC1,C2(300) for (a)1Tx/1Rx (b) 2Tx/1Rx (c) 3Tx/1Rx and (d) 4Tx/1Rx RZ transmitters	165
5.24	G2T-FSO curved track previous studies comparison	166
6.1	Link margins of (a) NRZ and (b) RZ transmitters for straight track G2T-FSO model	169
6.2	Number of required base stations for (a) NRZ and (b) RZ transmitters for straight track G2T-FSO model	171
6.3	Link margins of (a) NRZ and (b) RZ transmitters for Curved Track G2T-FSO model	175
6.4	Number of required base stations for (a) NRZ and (b) RZ transmitters for curved track G2T-FSO model	176
7.1	An overview of Hybrid RF/FSO and RoFSO configurations	184



LIST OF TABLES

2.1	Summary of contemporary technologies for internet access onboard trains	25
2.2	Advantages of FSO over RF communications	36
2.3	FSO challenges and mitigation summary	39
2.4	Various values of MPE and AEL for 850nm and 1500nm wavelengths	41
2.5	IEC 60825-1 laser classification system	41
2.6	Laser diode and light emitting diodes characteristics	43
2.7	Lasers wavelengths and semiconductor materials	44
2.8	Typical values of scattering particles characteristics	53
2.9	Typical parameter used in rain attenuation estimation	54
2.10	International visibility code	55
2.11	Summary of coherent and Non-coherent receiver parameters	60
2.13	Literature overview and comparison with the modeled system	72
2.14	Literature overview of key parameters comparison	74
3.1	Variations of horizontal Radii for different driving speed with curved track modeling parameters	87
3.2	Summary of G2T-FSO models equations	100
4.1	Straight track modelling parameters	104
4.2	Straight track theoretical parameters	106
4.3	Curved and double curved track base station position initial parameters	107
4.4	Double curved track theoretical parameters	111
4.5	Rain attenuation simulation parameters	120
4.6	Visibility data fog types characterization summary	122
4.7	Straight track G2T-FSO geometrical parameters	124

4.8	Curved and double curved track G2T-FSO geometrical parameters	125
4.9	Optisystem G2T-FSO link simulation parameters	125
5.1	Summary of G2T-FSO (NRZ) stright track link Eye diagrams and their relatitionship relative to weather and train position	132
5.2	Summary of G2T-FSO (RZ) stright track link eye diagrams and their relationship relative to weather and train position	137
5.3	Related research comparison	140
5.4	Summary of G2T-FSO (NRZ) curved track link at RC1(250)=2662m eye diagrams and their relationships	146
5.5	Summary of G2T-FSO (RZ) curved track link at RC1(250)=2662m eye diagrams and their relationships	151
5.6	Summary of G2T-FSO (NRZ) double curved track link at (RC2(250)=2667m) eye diagrams and their relationships	156
5.7	Summary of G2T-FSO (RZ) double curved track link at (RC2(250)=2667m) eye diagrams and their relationships	161
5.8	Related research comparison	166
6.1	Straight track G2T-FSO link power budget analysis for NRZ transmitters	173
6.2	Straight track G2T-FSO link power budget analysis for RZ transmitters	174
6.3	Curved track G2T-FSO link power budget analysis for NRZ transmitters for (RC1(200)=2667m)	178
6.4	Curved track G2T-FSO link power budget analysis for RZ transmitters for (R C1(200)=2667m)	179

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Considerations for Curved Track horizontal Alignment Radii	200
B	MATLAB Codes	208
C	Meteorological Weather Data Sample	213
D	FSO-G2T Optisystem Simulation Results Data Tables	210
E	FSO-G2T Link Power Budgets	224



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PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF SYMBOLS

β_{FOV}	-	Field of View Angel
λ	-	Wavelength
f	-	Frequency
c	-	Speed of light ($c=2.988 \times 10^8$ m/s),
$p(t)$	-	Normalized transmitted pulse shape
T_b	-	bit duration
t	-	Time
η	-	Quantum Efficiency
q	-	electron charge
$F(M)$	-	APD noise figure
I_M	-	average multiplied current
σ_{noise}^2	-	the variance of internal and external noises
$\sigma_{thermal}^2$	-	thermal noise variance
σ_{shot}^2	-	Shot noise variance
$\sigma_{Background}^2$	-	background illumination noise variance
$\langle i_{Thermal}^2 \rangle$	-	thermal noise current
τ	-	Transmittance coefficient
γ_T	-	atmospheric attenuation coefficient
L	-	propagation length
γ_{abs}	-	absorption coefficient
α_{abs}	-	effective cross section of absorption particle

N_{abs}	-	concentration of absorption particle
γ_{Scat}	-	Scattering coefficient
N_{scat}	-	cross section of Scattering particle
α_{scat}	-	effective cross section of Scattering particle
$\gamma_{ScatTotal}$	-	Total Scattering coefficient
x_0	-	particle size
$\gamma_{Rayleigh}$	-	Rayleigh Scattering Coefficient
γ_{MIE}	-	Mie Scattering Coefficient
N_p	-	number of particle per unit volume
A_p	-	the cross section area of the particle
α_m	-	Mie scattering cross-section
N_a	-	density of aerosol molecule
$R_{mm/h}$	-	Rain precipitation rate
γ_{Rain}	-	rain attenuation
γ_{fog}	-	fog attenuation
q_{Kruse}	-	Kruse distribution size of particles
q_{KIM}	-	Kim distribution size of particles
$L_{Geometrical}$	-	Geometrical loss
$\delta_{Coverage}$	-	coverage angle at Point C
β	-	coverage angle at Point G
δ_{Cant}	-	cant (or superelevation) angle
ζ	-	residual lateral acceleration
ζ_{max}	-	Maximum residual lateral acceleration
γ_{Tilt}	-	Tilt angle
ϖ	-	angle between Tx_A and Rx_A
P_{Total}	-	Total power
$P_{Transmitted(mW)}$	-	Total transmitted Power mW

N_{TX}	-	Number of Transmitters
LM	-	Link margin
$L_{Atmospheric}$	-	Total Atmospheric loss
L_{Tx}	-	Transmitter losses
L_{Rx}	-	Receiver losses
$N.B_{/10km}$	-	Number of Base Stations per 10km
$N.B_{/1km}$	-	Number of Base Stations per 1km
h	-	Planck's constant (6.63×10^{-34} Joules.Seconds).
α, k	-	rain attenuation coefficients
A_r	-	receiver aperture area
A_t	-	transmitter aperture area
B	-	Bandwidth
C	-	Arc length
d_H	-	Horizontal Distance parallel to rail track
d_v	-	Vertical distance parallel to rail track
E	-	Cant excesses
$E1$	-	Atom low Energy State
$E2$	-	Atom low Energy State
$FFOV$	-	Full field of view
G	-	Gain
g	-	acceleration of gravity
I	-	Cant deficiency
I_d	-	Dark current
I_{max}	-	Cant deficiency
I_p	-	received photocurrent
$L_{Coverage}$	-	Railway Track Coverage Length
L_p	-	transmission range
L_p	-	Pointing losses
M	-	APD multiplication factor
N_b	-	photons per bit (#Photon/bit)
P_{in}	-	received optical power

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